

NUTHELLA: A Simulation Tool for Generation IV Nuclear Reactors

Giovanni Lapenta, T-15

Access to energy is one of the pillars of civilization. How energy is generated contributes to defining a society. There is no doubt that we are at a critical point in the technological history of energy production. Legislation is being considered and passed to address the problem and serious policy decisions are being discussed and made that will shape the future of our society and of the environment. The duty of the scientific and technological community is to provide the public with reliable tools to arrive at an informed decision about energy policy.

A viable and proven source of energy is nuclear fission. Current reactors are basically still based on concepts developed in the early days of nuclear engineering. The U.S. DOE and the energy authorities of the European Union, Japan, and other countries have launched the Generation IV initiative [1] to consider new reactor concepts that hold the promise of solving some or all of the perceived pitfalls of nuclear energy production. Two main issues to address are: availability of fissile material and disposal of radioactive waste. If energy is to be produced in larger fractions from nuclear energy, the available fuel for current reactors would be severely limited, if the current prevailing paradigm remains true. In current reactors, the fuel is used once and it is not reprocessed to avoid the risks involved in the procedure. Furthermore the burned nuclear fuel is highly radioactive and it remains so for geological times.

Among the Generation IV reactors, one category is particularly promising: fluid-fuel recirculated reactors, critical or subcritical driven by particle accelerators. In such reactors, the fuel is treated and fully consumed on site. The most problematic nuclear waste materials, the actinides, are destroyed in the nuclear reactions developing within the reactor. In one stroke, the concept solves the problem of the insufficient use of fresh uranium and of the disposal of long-term radioactive waste. This concept, as all others pursued within the Generation IV initiative, needs to be investigated and analyzed for future development. While many experimental and technological issues are of extreme importance, in particular material and chemistry issues, we focus here on the safety and control of the new concept. The use of fluid-fuels is a largely unexplored concept for nuclear engineering. In the early years of the golden age of nuclear engineering, the concept was considered with the pencil and paper tools of the time. We have taken upon ourselves to contribute to bringing this topic into the 21st century.

In our previous experience within the European fission energy program, we developed a new formulation of the fundamental mathematical model for fluid-fuel reactors [2]. As can be expected, the model mixes complex physical processes including heat transfer, fluid dynamics, and neutron transport. The model is particularly challenging as the scales involved in such diverse processes cover many orders of magnitude.

We addressed such a very challenging multiphysics and multiscale process using some of the most modern simulation techniques. We are developing a new fully implicit coupled thermodynamics-fluid dynamics-neutronics code, NUTHELLA [3]. The key aspect of our approach is the use of the Newton-Krylov method to solve the highly nonlinear coupled equations of the model. Furthermore, we have developed a new predictor-corrector

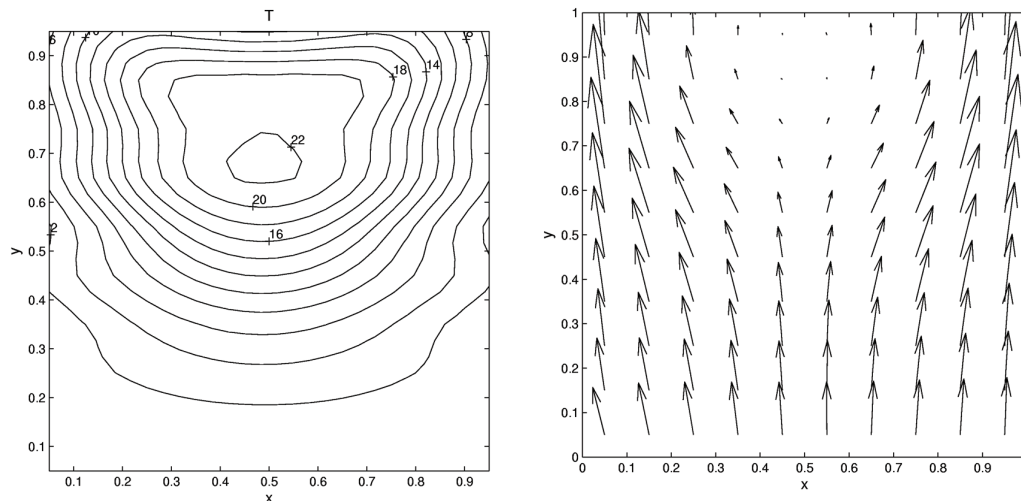


Fig. 1. Typical result of the new NUT-HELLA code. Flow pattern (right figure) and temperature (left figure) on a vertical section a fluid fuel reactor. The temperature is in Kelvin above average and the flow speed is proportional to the arrow length.

preconditioning technique to increase the efficiency of the method [4].

Below we show a typical reactor state computed with the new code. In the example, an abnormal transient leads to localized temperature intensification. A vicious cycle is created, where the hot region diverts the flow and heats up further. This dangerous possibility is avoided in current designs by the addition of flow guiding walls that prevent the flow from being diverted away from hot spots. This is but an example of the predictive capability of our new code that can be used for the design and operation of fluid-fuel nuclear reactors.

For more information contact
Giovanni Lapenta at lapenta@lanl.gov.

- [1] <http://gen-iv.ne.doe.gov/>
- [2] G. Lapenta and P. Ravetto, "Neutron Model for the Safety Assessment of Actinide Burners with Circulating Fuel," *9th International Conference on Emerging Nuclear Energy Systems ICENES'98* (1998).
- [3] G. Lapenta, "Mathematical Models of the Coupling of Neutronics and Thermal-Hydrodynamics in Circulating Fuel Nuclear Reactors," *M&C 2005: Mathematics and Computation, Supercomputing, Reactor Physics and Nuclear Biological Applications* (2005).
- [4] G. Lapenta, J. Jianwei, "Predictor-Corrector Preconditioners for Newton-Krylov Solvers," *J. Comput. Phys.*, submitted.